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Cloud Distributions as Indicators of Tropical Storm Displacement

THOMAS J. KEEGAN

3 August 1976

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METEOROLOGY DIVISION PROJECT 6698
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AIR FORCE SYSTEMS COMMAND, USAF

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER:

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Chief Scientist

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This is a preliminary report on ~~the~~ a use of satellite cloud imagery ~~as a device~~ to forecast ~~the movement of~~ tropical cyclones & movements.

The spatial distribution of cloudiness implicitly indicates information about recent or ongoing processes in the atmosphere. Assuming that, as with other parameters, the cloud distribution represents a set of initial conditions, it is reasonable to expect that forecast information can be extracted from these initial conditions. The problem with using satellite imagery as a self-contained forecast tool has been the difficulty in handling the data processing. cont on 1473B

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20. Abstract (Continued) with speed. human

The Man-computer Interactive Data Access System (McIDAS) is a flexible data management system ~~which has~~ the advantages of both ~~the~~ decision-making ~~ability of the human~~ and the ~~speed of the~~ computer. With McIDAS it is relatively simple to assemble composites of images of storms with similar displacement characteristics. These composites reinforce the cloud or cloudless features common to the individual cases and mute ~~the~~ randomly distributed clouds. Investigations of typhoon cloudiness in the Pacific indicate that there are different characteristic cloud distributions preceding storms that recurve and those that stay on westerly tracks. In particular there is a 'confluence' of ~~the~~ outflow cloudiness from the storm with the clouds of a mid-latitude frontal system in the case of low-latitude westward moving storms in the Philippine and South China Seas. Characteristic cloud patterns associated with other types of storm systems are also suggested by the analysis.

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Preface

Nothing could have been accomplished with the McIDAS equipment without the dedicated efforts of Mr. Robert F. Myers of the Meteorology Division. The obstacles he overcame are too numerous to list. In this work he had indispensable assistance from Messrs. Harold Pratt and Barry Mareiro of Regis College. Mr. Pratt also developed the special programs needed to perform the various imagery statistics. Finally, Mr. Joseph Pazniokas of the Mesoscale Forecasting Branch volunteered to operate the McIDAS. His monitoring of the input and output was instrumental in meeting deadlines. I offer my sincere thanks to all these people for their help.

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Cloud Distributions as Indicators of Tropical Storm Displacement

1. INTRODUCTION

1.1 Background of Tropical Storm Reconnaissance

The U. S. Air Force and Navy have traditionally provided aircraft weather reconnaissance support to meet their own needs in remote locations as well as the needs of the National Weather Service. Over the past few years, due to a variety of pressures, resources to support aircraft reconnaissance have been shrinking drastically. This austerity has hit the Joint Typhoon Warning Center (JTWC) on Guam particularly hard. JTWC has the storm warning responsibility for the Pacific Ocean north of the equator between the dateline and 90°E in the Bay of Bengal. In addition to the support provided the military establishments in the area, reconnaissance reports and storm forecasts are also available to the weather services of the western Pacific nations. In the past both Air Force and Navy had aircraft supporting this mission. Since 1972 only the 54th Weather Reconnaissance Squadron, Air Weather Service has been available for operations and the AWS is under pressure to replace that squadron and rely entirely on satellite, conventional, and radar data.

(Received for publication 3 August 1976)

In response to this pressure, the JTWC initiated the Selective Reconnaissance Program (SRP) in 1972.[1] This is a program to develop an effective mix of aircraft and satellite reconnaissance. Comparisons of position and peak wind speed based on the two reconnaissance methods have shown that satellite accuracy matches that of the aircraft if the storm has a detectable eye and its position can be supported by a landmark. At night, or without a landmark, or without an eye, the comparison between the two systems suffers. Overall though, the SRP has proved to be a cost-effective procedure. Its success is in no small measure due to the development of a technique by Dvorak[2] for estimating the peak wind speed in tropical storms from cloud features identifiable in satellite imagery.

1.2 Current Forecasting Practices

Tropical cyclones present some rather special forecasting problems. These storms develop and spend most of their lives over water and thus do not pass through a dense observing network. Furthermore, in the tropics atmospheric dynamics are defined by the wind systems alone. The geostropic relationship breaks down in the lower latitudes, and the diurnal variation in temperature is greater than the longer term variations. Computers are used in some forecasting techniques but the techniques are based on some elegant climatology and/or rules of thumb, or a very simplified dynamic model rather than the physics of the systems. Most actual field forecasting is based on persistence, climatology, and intuition. It is therefore very easy to see why the JTWC places so much emphasis on position reports. Any error in the speed or direction of the storm in the past is automatically carried through and amplified for the future position.

1.3 Comparison of Aircraft and Satellite Observations

As mentioned above, much of the time there is excellent agreement between aircraft and satellite position and intensity reports. Positioning from satellite imagery becomes difficult when there is no clear-cut eye or textured cloudiness to define the center of circulation. Aircraft reconnaissance sometimes report sizable displacements between the pressure, wind, and cloud eyes or between the sea-level and 700-mb positions of the eye. Satellites provide meso- and large-scale cloud distribution, type, and topography but will not be able, in the foreseeable future, to provide measurements of central pressure and sea state from which to make peak wind estimates or to give any of the direct measurements possible with a fully

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1. Arnold, C.P., Jr. (1975) Selective reconnaissance program of the western north Pacific, B. Amer. Met. Soc., **56**:362-371.

2. Dvorak, V.F. (1975) Tropical cyclone intensity analysis and forecasting from satellite imagery, Mon. Wea. Rev., **103**:420-430.

equipped reconnaissance aircraft. This lack of quantitative data in satellite observations is probably not too serious a handicap, though, since it is only used now in defining the initial conditions and not in any forecast equations.

In the cloud fields viewed by satellites there is also a set of initial conditions. The clouds reflect processes that are going on or have recently gone on in the atmosphere just as do fields of pressure, temperature and vertical velocity. Clouds implicity contain information about physical processes going on in the atmosphere, certainly not all physical processes, but very probably some important ones. Thus there would seem to be just as rational a basis for believing that cloud fields contain information about the future as well as the present state of the atmosphere as there is in believing that the pressure field has predictive value.

2. APPROACH

2.1 Basic Hypothesis

JTWC requires a forecast method that is based on human interpretation of satellite imagery. Some computer power is available, but not to the extent of being able to handle imagery data rates. As we have seen, except for establishing position, there is not much equivalency between aircraft and satellite observations. It stands to reason then that we should start off by asking what it is that we can get from cloud images rather than by trying to force from imagery the same type of information produced by completely different observational systems. Thus it is assumed that it is reasonable to ask, for example, if there are any cloudy or clear areas consistently located with respect to the center of a typhoon 24 hours prior to recurvature, or 12 hours or 48 hours. The forecaster in the field, who has only periodic "snapshots" available, needs a technique which specifies the significant cloud features similar storm systems have in common and/or the differences between storms that move on different paths. Preferably this information should be available in a single image, although a short time series of images would be acceptable.

A common and powerful analysis technique to use when examining the characteristics of data fields, as contrasted with point values, is to composite the data. In this technique, the average value of the field, accompanying or preceding some event, is derived to learn if there are any features common to all or most of the individual cases in the sample which have diagnostic or predictive value. Compositing reinforces significant features and mutes the random details of data fields.

Shea[3] demonstrates one type of composite by his computation of tangential and radial components of winds in hurricanes. He assembled wind values from a large number of storms and then averaged them with respect to their position relative to the radius of maximum wind. Dvorak[2] used another type of compositing in his study of current and predicted tropical storm intensity. By visually examining the cloud characteristics in the vicinity of a storm, he was able to associate features of the central overcast, eye, and cloud banding with the peak wind speed intensity in the storm. The difficulty with the Dvorak approach is that it requires an analyst with an extraordinary ability to retain the significant features of dozens of images in his mind. Most people are not that gifted, and the selection and sorting of data become an unmanageable task. The Shea approach also runs into trouble when applied to imagery. It is basically a method for stretching a spotty data base to achieve good coverage. If there is anything from which satellite imagery does not suffer, it is spotty coverage. Its problem is quite the opposite.

The computer processing of imagery is a difficult task. Algorithms for defining cloud characteristics have to be developed and cases have to be selected, sorted, and filed from hard-copy photographs. This also involves the shuffling and management of unwieldy amounts of pictures. Finally, a digital printout would not be particularly appropriate as the final output at a remote operational site.

2.2 Man-computer Interactive Data Access System (McIDAS)

The nature of the problem is such that, outside the immediate area of the storms (the region investigated by Dvorak), the cloud fields will be affected by longitude, latitude, season, and possibly the size or stage of development of the storms. All these potential stratifying criteria complicate the data management problem. Any given storm may be a component in several different stratifications. The files of pictures would become a problem to store, not to mention to examine critically in the analysis process. To handle this problem, a device is needed which allows one to have rapid access to images, to process rapidly the data contained in them, and to regenerate an image of processed data. Such a system is the McIDAS.[4] It is a computer which is designed to interact to decisions made by the operator on the basis of a CRT display of the digital data in the system

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3. Shea, D.J. (1972) The Structure and Dynamics of the Hurricane's Inner Region, Contract Report NOAA N 22-65-72(G), NSF GA 19937, Colo. St. Univ., Atms. Sci. Paper No. 182.

4. Suomi, V.E. (1975) Man-computer Interactive Data Access System (McIDAS). Continued Development of McIDAS and Operation in the GARP Atlantic Tropical Experiment. Final Report, Contract No. NASA-CR-143818, Wisconsin Univ.

storage. McIDAS was originally designed to derive winds based on the displacement of clouds from one geosynchronous satellite image to the next. For these vectors to have any meaning at all, their initial and final positions must be known to the limits of the satellite's spatial resolution. The unique feature of the McIDAS is that the software allows one to exploit the known locations of landmarks as displayed on the screen in order to derive the precise equation of motion of the satellite. With this information, the location of any picture element can be achieved to an accuracy consistent with the accuracy of the landmark definition. With care this should be one picture element. The main components of the system are the data input devices; the central processing unit; supplementary disk storage of both programs and imagery; an analog disk which can store, for instantaneous retrieval, 250 TV frames of imagery; a CRT display; an electronic cursor; and a keyboard for entering operating instructions. Input can be in the form of live, stretched Geosynchronous Operational Environmental Satellite (GOES) data, analog data relayed over the telephone line, through computer tape, or through a slant-track tape recorder modified to record all digital imagery data transmitted by GOES. Pictures on the video disk can be enhanced in black and white or color and assembled into animated loops. If navigated, that is, if the relationship between picture elements and geographic coordinates has been determined, cloud-motion vectors can be computed. If the image data are kept on the digital disk, the cursor can be used to delineate areas to be numerically processed, to select points for which brightness or temperature values are desired, to shift the picture position on the CRT, or to blow up the image so as to repeat each picture element a number of times (very critical in selecting the exact picture element of a landmark).

For this investigation many of the features that contribute to the precision of the McIDAS system were not required but some additional programs had to be developed. Specifically they were:

(a) Data Averaging – computes the average brightness of the contents of two digital disk areas. If one area is already an average of several cases, the old average and the new addition are weighted in proportion to their contributions to the new average.

(b) Data Removal – removes an individual image from a previously computed average and restores the average as it was before that case was included.

(c) Data Differencing – computes the difference in brightness between the contents of two digital disk areas.

(d) Image Positioning – rewrites the image data on the digital disk. A starting picture element is selected so as to position a selected image feature at a preselected point on the display. This is used in the computation of the composite field relative to the storm centers rather than to the geographic location.

3.1 Data Base

An investigation of this type requires emphasis on data quantity rather than quality. This is a fortunate circumstance, since quality data such as those from DMSP or GOES satellites are not available in large quantities, and the data from the NOAA archive, which are of degraded spatial resolution, have daily visual and twice daily infrared global coverage since 1973. These data are contained on computer tape and they are also illustrated in a monthly booklet,[5] which can be used for browsing or quick checks of the data. Each hemisphere is formatted in a polar stereographic projection inscribed in a square of 2048 rows and columns of data. When those points that fall beyond the map bounds are subtracted out, the cloud information has an average spatial resolution of about 9 km.

For this study the period of record runs from July 1973 through January 1976. During this time there were 40 storms that reached typhoon intensity in the western Pacific Ocean. This represents approximately 200 days of data. Only storms that reached typhoon intensity were used in the investigation, but on many of the days used the storms were well under typhoon strength.

Figure 1 illustrated how the data can be presented on the McIDAS display. Figures 1a and 1b are at reduced resolutions of every 4th row and 3rd column and 2nd row and 2nd column, respectively; 1c is full resolution and 1d has each row and column repeated three times. Normally, data were displayed in the 1/2 resolution format for Figure 1b. It was thought that this size included enough of the area around the storms under investigation to portray any of the cloud systems associated with factors that could affect or be affected by the storm system itself.

3.2 Climatology of the Period of Record

Typhoons in the western Pacific Ocean follow two principal tracks (see Figure 2). One is a WNW path from the area of 10°N, 150°E, across or close to the Philippine Islands and into the South China Sea (Type A). The other major track originates in the same region, but the storms have a more northerly component to their directions and recurve to the NE around 30°N (Type B). The longitude of recurvature can vary depending on the longitude of formation and the northerly component of motion. Less frequently, storms travel northward out of the JTWC's area of responsibility (Type C). Finally, there are the storms that do not fit a well-defined pattern (Type D). During their existence they may assume the characteristics of any, all, or none of the above categories.

5. National Oceanic and Atmospheric Administration (1973) Environmental Satellite Imagery, Key to Meteorological Records Documentation.

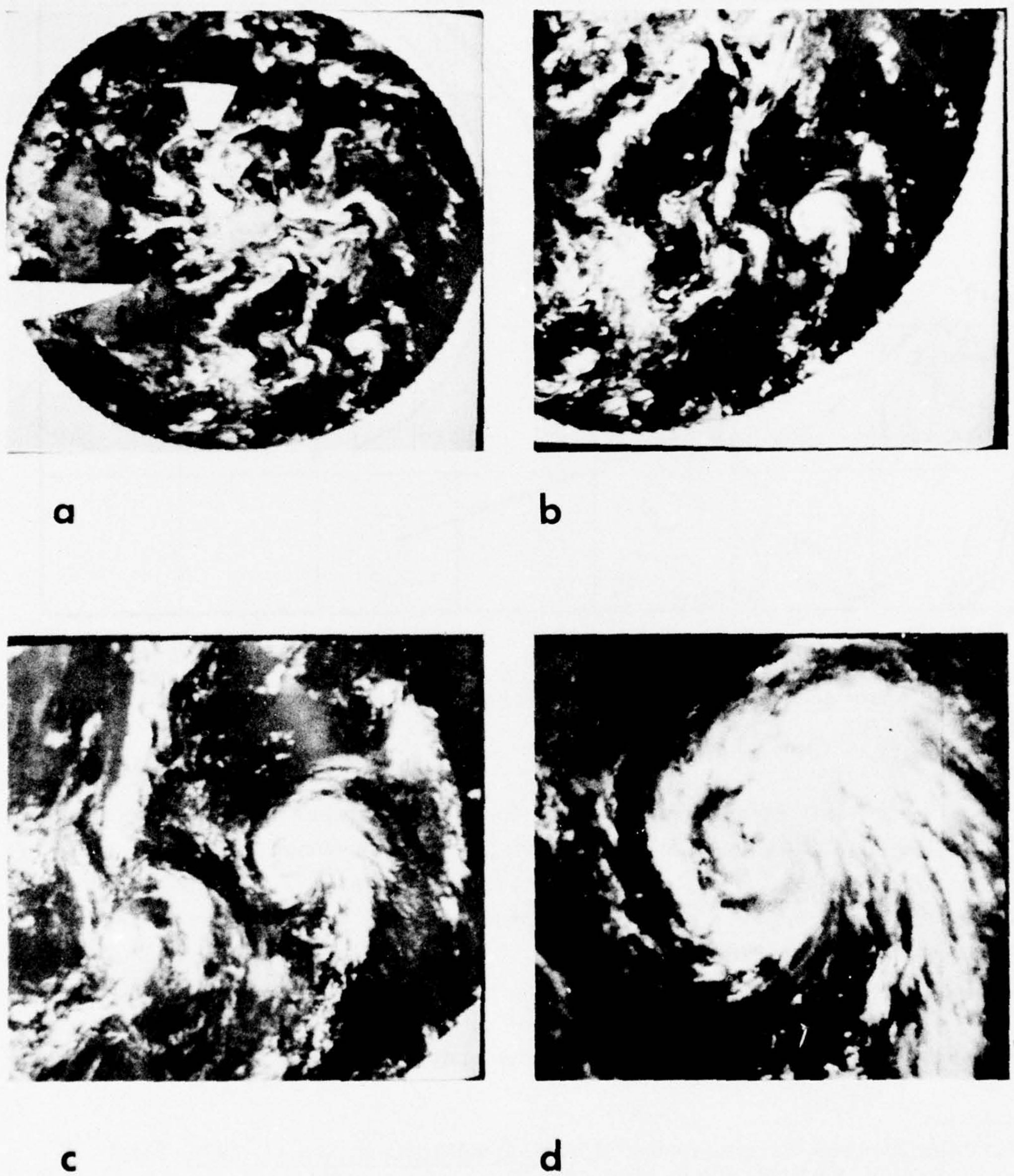


Figure 1. McIDAS Display of NOAA Archive Data Resolved at (a) Every 4th Row and 3rd Column; (b) Every 2nd Row and 2nd Column; (c) Every Row and Column; and (d) Every Row and Column Repeated 3 Times

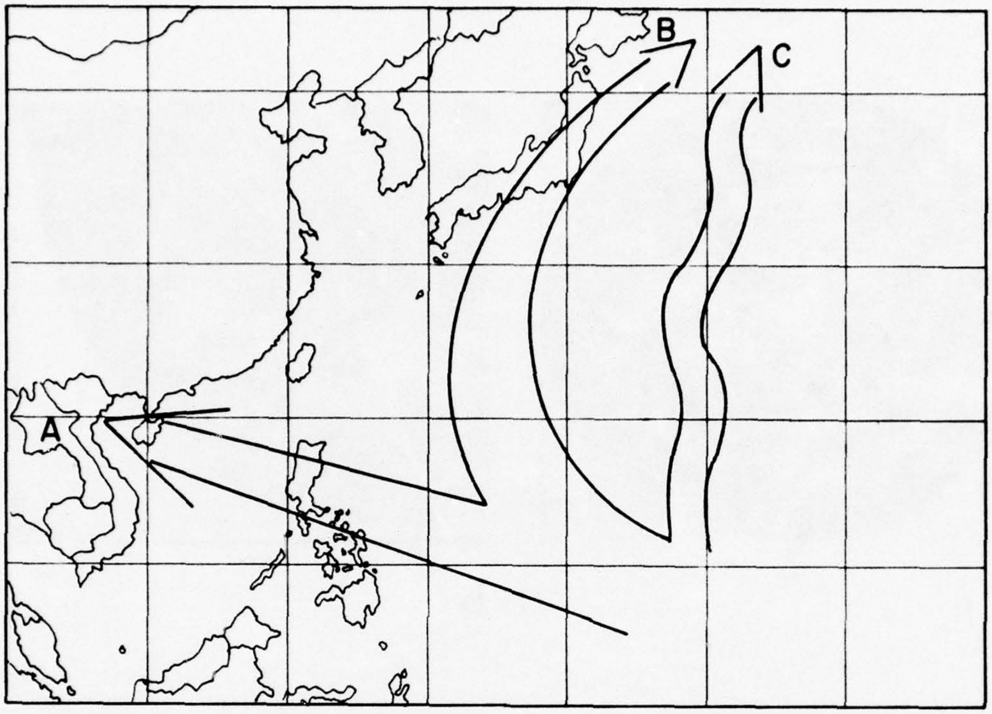


Figure 2. Typical Western Pacific Tropical Cyclone Tracks. Type D storms constitute a miscellaneous collection of storms which do not clearly resemble the other 3 types

There is a strong seasonal character to the storm tracks from 1973 through 1975. The data in Table 1 were taken from the *Annual Typhoon Reports* for 1973, 1974, and 1975.[6, 7, 8] The first row shows the number of days each month at 00Z for which data for storms that reached typhoon strength were listed in the reports. The second row shows the number of days these storms were located north of 25°N. That 95 percent of the time that storms travelled north of 25°N occurred during July, August, and September, is a forecast aid in itself. As an independent check, the same computation for 1971 and 1972 was made and gave the comparable result

6. Joint Typhoon Warning Center (1973) Annual Typhoon Report, 1973, Fleet Weather Central, Guam, Marianas Is.

7. Joint Typhoon Warning Center (1974) Annual Typhoon Report, 1974, Fleet Weather Central, Guam, Marianas Is.

8. Joint Typhoon Warning Center (1975) Annual Typhoon Report, 1975, Fleet Weather Central, Guam, Marianas Is.

that 45 of 50 typhoon days (90 percent) that occurred north of 25°N did so during the same three months of the year.

Table 1. Number of "Typhoon Days" (top) and Number of Days the Typhoons Were North of 25°N (bottom) in the Western Pacific During 1973-74-75

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Typhoon days	5	0	0	0	5	7	34	46	47	67	27	2
Typhoon days north of 25°N	0	0	0	0	0	0	14	25	20	2	1	0

Typical storm tracks are shown in Figure 2. Type A storms constituted 43 percent of the 3-year sample; Type B, 27 percent; Type C, 10 percent; and Type D, 20 percent. One unusual feature of the Type A storm tracks was that in the 1973 to 75 period they were centered, on the average, 3 to 5 deg of latitude further north than for the years 1971 and 1972.

In order to utilize this approach fully, the data sample should be large enough to construct significant composites for each location stratified by season, heading, and speed. The 3-year sample available meets this condition only marginally in certain times or locations. One difficulty is associated with the pronounced year-to-year variations. For example, 1973 had no Type B (recurving) typhoons. It is possible that the extended circulation features that caused this to happen also caused changes in the cloud fields associated with Type A storms.

Such meteorological considerations argued for a stratification based primarily on location. In addition, since the data are presented in a polar stereographic format, compositing of storms located more than 4 or 5 deg apart introduces significant distortions in the scaling. Furthermore, approximately half the area included in the study is close enough to land so that systematic orographic effects introduce additional "noise" if storms that are well out to sea are averaged with those near Asia.

Figure 3 shows the number of storm days that occurred in each 5° square between 1973 and 1975. There are only 6 squares that have 10 or more storm days. Guidelines extracted from these small samples are useful as interim solutions, especially if they are internally consistent with other classifications.

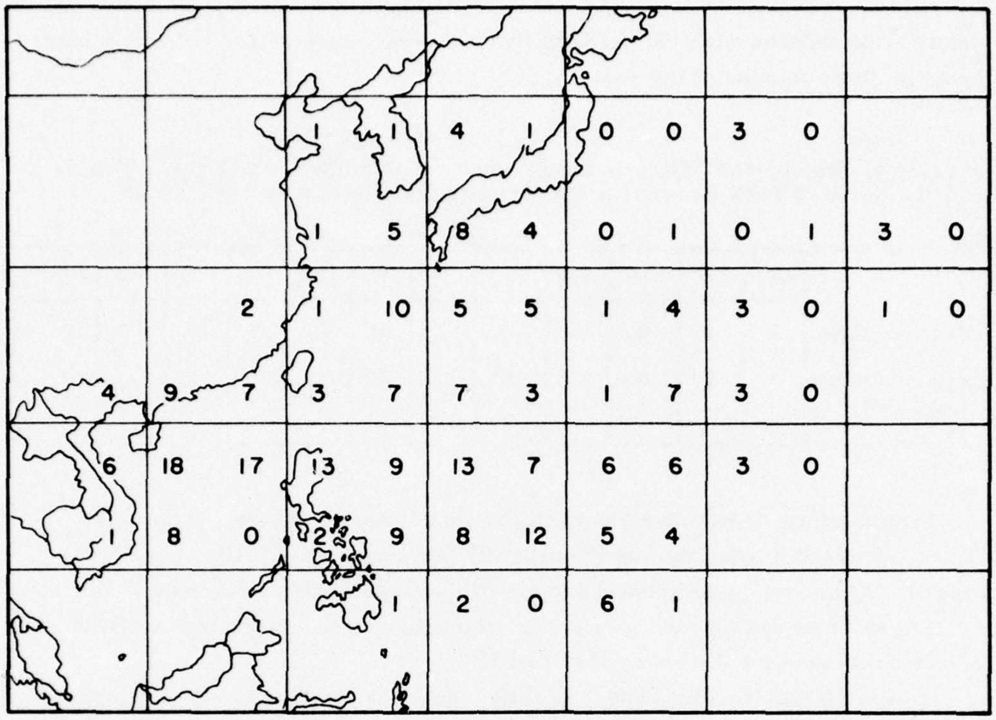


Figure 3. Number of Reports by JTWC during 1973, 74, and 75 at 00Z of Tropical Cyclones that Achieved Typhoon Strength in 5-deg Latitude-longitude Boxes

4. ANALYSIS

4.1 Storms in the Area Between 15° and 20°N, and 130° and 135°E

Table 2 presents the salient features of storms located between 15° and 20°N and 130° and 135°E. The storms are ordered by increasing angle of heading for the 24 hours starting at 00Z on the listed date and the rank of their motion and maximum wind speed is listed next to the comparable value.

Two strong tendencies are apparent from an examination of the listing. The 1975 storms had a more northerly heading than the 1974 storms, and the more northerly headings tended to occur earlier in the year. There may very likely be an explanation for this in a comparison of the general circulations of the two years, but it is beyond the scope of this report.

Figure 4 is a grid for the sector of the northern hemisphere used in the illustrations that follow. Figure 5 illustrates storms Nos. 2 and 3, their average and their difference for the purpose of allowing the reader to examine how the features

Table 2. Features of Storms Located Between 15° and 20°N, 130° and 135°E

Storm No.	Date	Heading (deg)	Speed (kt)	Rank	Intensity (kt)	Rank
1	10/26/74	267	13	2	60	4
2	11/26/74	270	11	5	105	1
3	11/5/74	274	11	6	100	2
4	7/1/74	277	4	10	40	8
5	10/9/74	280	12	4	35	9
6	11/25/74	286	6	9	85	3
7	9/20/75	293	13	3	55	6
8	7/31/75	298	2	11	60	5
9	7/2/74	300	8	8	30	10
10	8/1/75	320	14	1	50	7
11	10/2/75	340	11	7	30	11

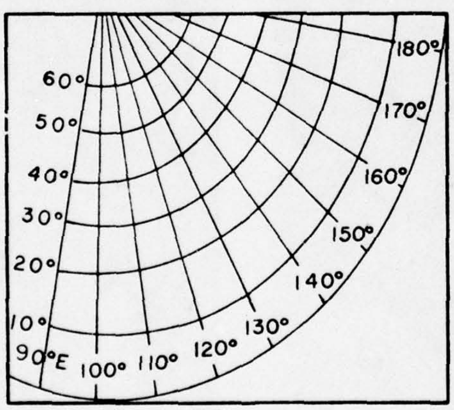


Figure 4. Geographic Grid of the Photographs of the McIDAS Display Used in This Report

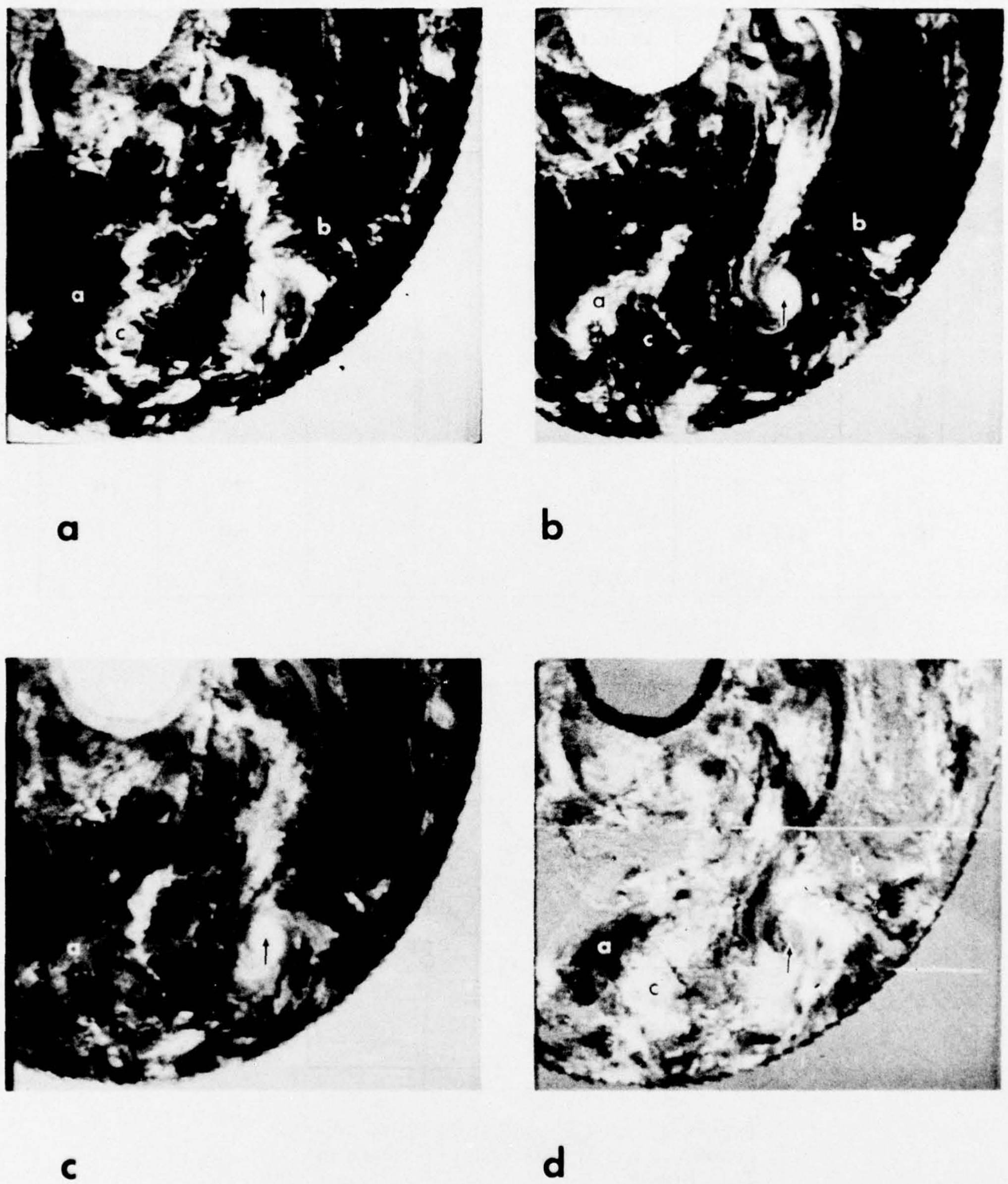


Figure 5. Tropical Cyclones on (a) Nov. 5, 1974; (b) Nov. 26, 1974; (c) the Composite Brightness; and (d) the Difference in Brightness of (a) Minus (b). Centers of the storms are marked by an arrow. Points a, b, and c illustrate the effects of adding or subtracting various combinations of cloudy and clear areas

of the individual storms contribute to the combinations. For example, a neutral gray shade in the average (point a, Figure 5c) usually represents a combination of bright clouds in some of the individual images (point a, Figure 5a) and clear areas (point a, Figure 5b) in others or some combination of white clouds, clear and gray clouds. In a difference between images a neutral gray means little or no change in brightness (point b in Figures 5a, 5b, 5d, and at the storm centers). A bright area in the average, such as at the storm centers means that the individual images were composed of bright clouds and a dark average means the individual images were mostly clear. A bright area in the difference (point c in Figures 5a, 5b, 5d) means that a clear area was subtracted from a bright cloudy area while a dark area in the difference means the opposite (point a in Figures 5a, 5b, and 5d).

Figure 6 shows the average of all 11 storms listed in Table 2 as well as the average of storms Nos. 1 to 5 and 8 to 11. Features of storms in this location as shown in Figure 6a are:

(a) Considerable cirrus outflow to the southwest,

(b) Little cloudiness to the east centered about the latitude of the storm,

(c) A clear moat ahead of the storm indicative of the zone of subsidence typically located in that position.

The average of the 5 storms on the most westerly headings and the average of the 4 storms with the most northerly headings show some rather interesting differences. For the storms which have the more northerly headings (Figure 6c), the cirrus outflow is more predominant in the eastern semicircle. For the more westerly tracking storms there appears to be an extension of the cirrus outflow from the tropical cyclones to the northeast into or above the cloudiness associated with a midlatitude frontal system. Note how this confluence appears in individual storms in Figures 5a and 5b, which are 2 of the 5 storms included in Figure 6b. In Figure 5b, the confluence is just about to be made. The only storm in this set of 5 storms that did not display this confluence feature on, or within a day of being in this location, was storm No. 4 which was a Type B storm prior to recurvature.

Figure 7a is the composite of the 4 fastest moving storms (Nos. 10, 1, 7, 5) with speeds ranging from 14 to 12 kt. Figure 7b is the composite of the 3 slowest moving storms (Nos. 6, 4, 8) with speeds of 2 to 6 kt. Stratification of the storms in this area on the basis of speed of motion did not produce any suggestion of identifiable cloud distributions. There is nothing that characterizes either case very strongly unless it is the larger extent of the brightest cloud cover in the case of the slower moving storms. Stratification by peak wind speed was not tested at this point since it was felt, on the basis of Dvorak's[2] work, that the information most probably would lie in features of the near-storm cloudiness that are too small to be detected with data of this resolution. In view of features of the storms in the box 10 deg to the west, described in the next section, it should be noted that the 3 storms

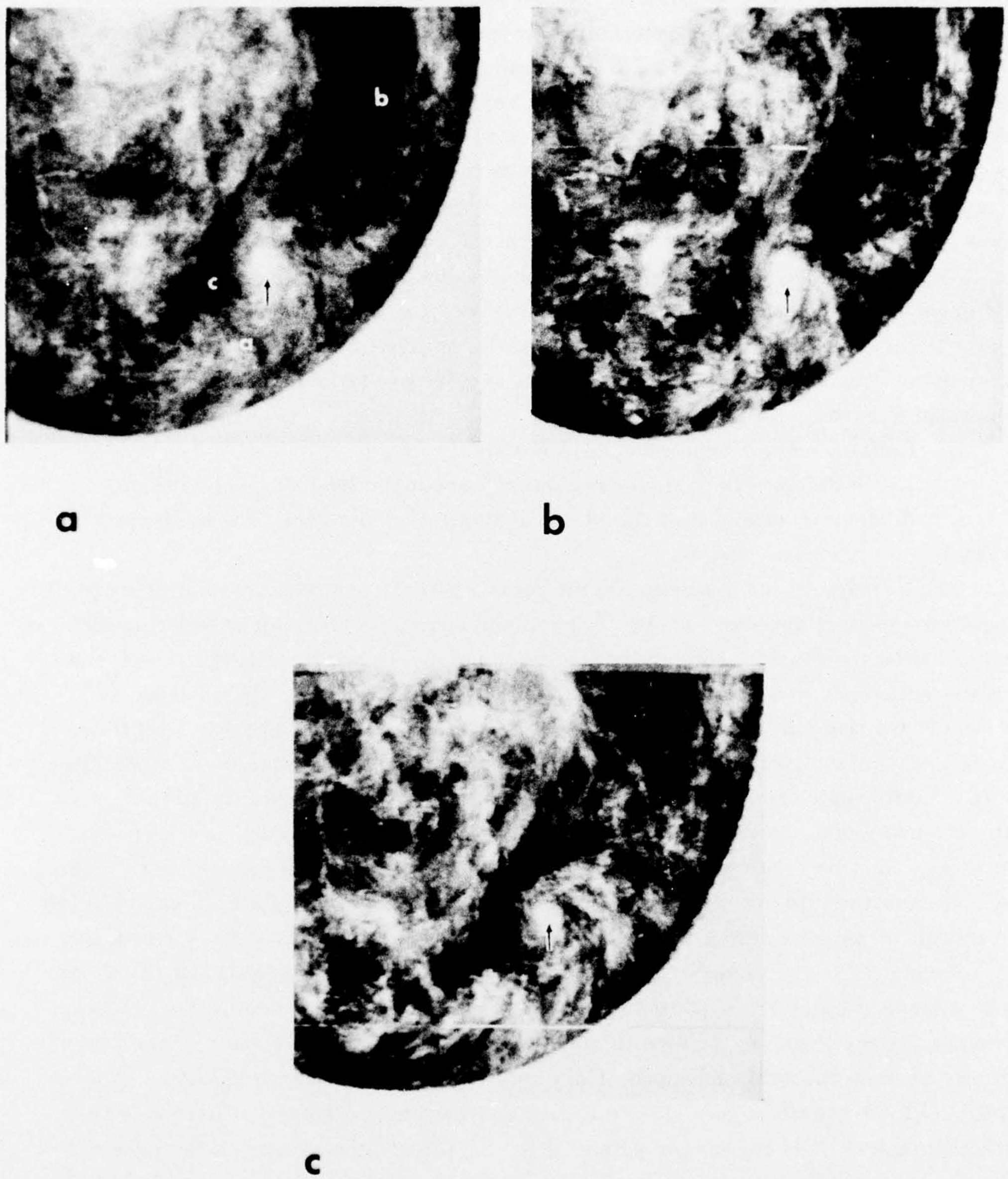


Figure 6. Composite Brightness of Storms Located Between 15° and $20^{\circ}N$, 130° and $135^{\circ}E$; (a) All 11 Storms; (b) 5 Storms with the Most Westerly Heading; and (c) 4 Storms with the Most Northerly Heading. Features a, b, and c are described in the text. Arrow indicates composite storm center

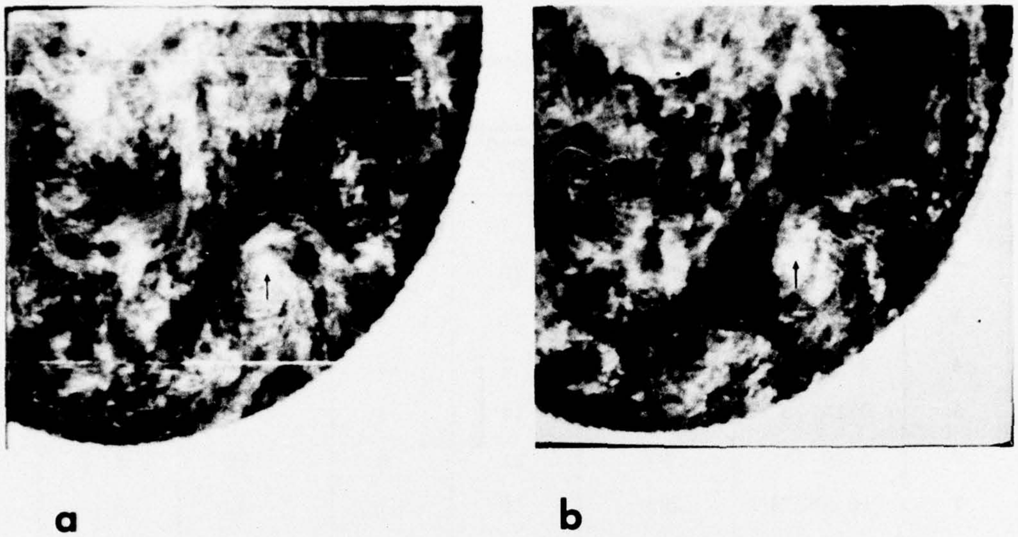


Figure 7. Composite Brightness of Storms Located Between 15° and 20°N, 130° and 135°E; (a) 4 Fastest Moving Storms; (b) 3 Slowest Moving Storms

with the most westerly heading are among the most intense while the 3 most northerly heading storms are among the least intense.

4.2 Storms in the Area Between 15° and 20°N, and 120° and 125°E

This 5-deg box is dominated by the Philippine Island of Luzon and is one of the most typhoon-frequented areas of the world. Most of the storms in the region are Type A although an occasional Type D might occur. The island of Luzon (only 1 storm passed south of Luzon) did not present a sufficient obstacle to dissipate the tropical cyclones that passed over it during 1973 to 75. There is, however, a considerable diminution of the peak wind as the storms pass over it. When the storms continue into the South China Sea some become more and some less intense than they were in the Philippine Sea.

Table 3 lists the storms in this box ranked in the same manner as was done for Table 2.

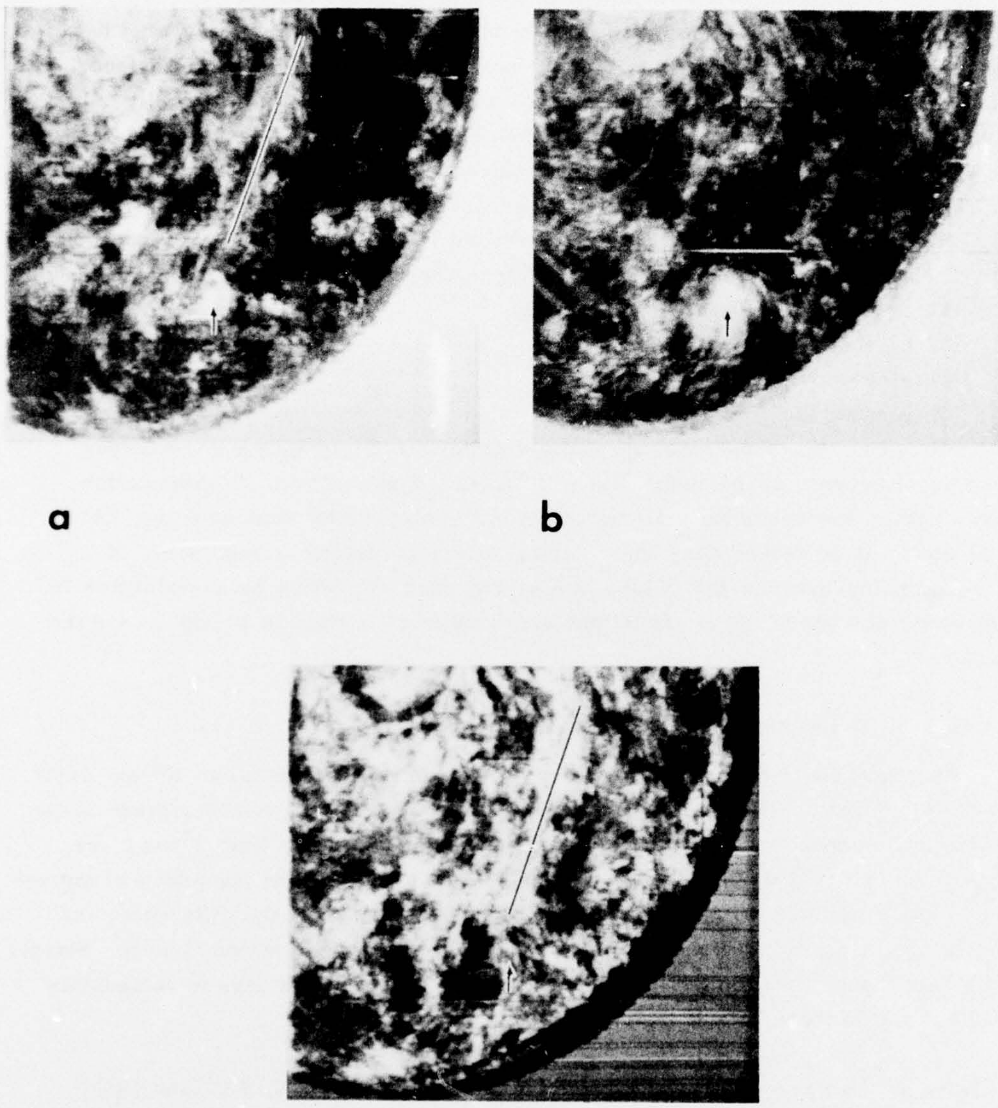
In this area stratification of the data by heading has not also stratified the data by year as it did in the box 10 deg to the east. It does form an approximate stratification by intensity in that storms 9 through 13 are, with one exception, greater than 90 kt while storms 1 through 5 are less intense than 90 kt, with one exception. The composites of the westerly moving storms (Nos. 1, 2, 3, and 4) and the northwesterly movers (Nos. 9, 11, 12, 13) and the differences between the composites

Table 3. Features of Storms Located between 15° and 20°N, 120° and 125°N

No.	Date	Heading (deg)	Speed (kt)	Rank	Intensity (kt)	Rank
1	10/23/74	242	7	11	70	7
2	10/12/73	264	18	1	40	13
3	11/28/74	271	11	5	90	3
4	9/3/73	273	4	13	60	12
5	9/18/75	280	14	2	65	9
6	6/10/74	283	11	6	70	8
7	10/28/74	285	10	7	80	6
8	10/11/74	289	9	10	65	10
9	7/20/74	294	14	3	90	4
10	10/16/74	298	14	4	65	11
11	11/7/74	300	10	8	95	2
12	10/8/73	316	7	12	90	5
13	10/7/73	323	10	9	120	1

are shown in Figure 8. Storm No. 10 was not included in order that the composite of the storms with northwesterly headings would include the most intense storms also. The suggested relationship between heading and intensity at this location is in the opposite sense to that found 10 deg eastward, as discussed above. Figure 8c, the composite difference, shows agreement with the results discussed in the area 10 deg eastward, that is, the more westerly moving storms display a confluence between the cirrus outflow and polar frontal cloudiness.

Slow moving storms (Nos. 1, 4, 8, 12) also showed this cloud axis as compared with fast moving storms (Nos. 2, 5, 9, 10), however of the 4 cases in the slow composite, 2 were common with the westerly moving composite and may have weighted the composite out of proportion to their significance. The same situation exists when comparing storms in the northern part of the box with those in the southern part. Storms in the northern part of the box (Nos. 1, 2, 8, 12) displayed the cloud confluence while those in the south (Nos. 3, 6, 9, 10) did not. However the northern storms had 3 cases in common with the slow storms and the southern had 2 common cases with the fast storms. What is rather surprising, if it is significant, is that



a b

c

Figure 8. Composite Brightness of Storms Located Between 15° and 20°N, 120° and 125°E; (a) 4 Storms with Most Westerly Heading, (b) 4 Storms with Most Northerly Heading, and (c) the Difference (a) Minus (b). Arrow indicates composite center. Black and white line is axis of confluent cloudiness

the northern storms, which did not pass directly over Luzon, generally moved slower than those that were subjected to the barrier of the island.

At this point it might be well to try to interpret the significance of what has been observed in this 5-deg square at the northern end of the Philippine Islands. It is one of the more data-rich boxes in the sample and contains essentially only Type A storms. It is also worth noting that 9 of the 13 storms occurred in October or November and only 2 earlier than September. This is consistent with the data in Table 1 which showed that fall storms generally stayed south of 25°N.

The composites show a tendency for the outflow from the storm to blend with the circulation in a midlatitude frontal system when the storm is

(a) predominantly westerly in heading,

(b) comparatively weak in intensity,

(c) slow-moving,

(d) passing north of Luzon.

Actually storm No. 1 did meet all of these criteria. It will take a much larger sample, however, to establish which criteria, if any, occur in combination and whether the converse criteria and their combinations also hold up. At this point, it is indeed very encouraging to get as strong a suggestion of a relationship between the clouds and storm characteristics as is exhibited in this area, and one which is consistent with conditions in the box 10 deg toward the east.

4.3 Storms in the Area Between 15° and 20°N, and 125° and 130°E

As a spot check of the typhoon cloud conditions observed between 15° and 20°N in the 5-deg boxes bounded on the west by 120°E and 130°E, a test was made in the middle box bounded by 125°E on the west. In Table 4, storms Nos. 1 and 2 are Type A and storm No. 3 is Type C. The difference between the composite of storms No. 1 and 2 and storm No. 3 is shown in Figure 9. Again, in the difference, the confluence of the cloudiness in the case of the Type A storms shows clearly. Storms No. 1 and 2 also were included on the previous and subsequent days in composites in the boxes to the west and east.

Table 4. Features of Storms Located Between 15° and 20°N, 125° and 130°E

Storm No.	Date	Heading (deg)	Speed (kt)	Intensity (kt)
1	11/27/74	266	11	115
2	11/6/74	292	13	90
3	7/14/73	360	6	60

Figure 9. Difference of the Composite of 2 Type A Storms on Nov. 6 and 27, 1974 and a Type C Storm on July 14, 1973. Arrow indicates composite center

4.4 Storms in the Area Between 5° and 10° N, and 140° and 145° E

Figure 10 shows the composite of two Type A storms on the first days of their formations, Nov. 3 and 21, 1974. They both have the same heading, 311 deg, approximately the same speed, 8 and 11 kt, and peak winds of 25 to 35 kt, respectively. In this case, there is no cloud band to the northeast. Examination of other

Figure 10. Composite of 2 Type A Storms, Nov. 3 and 21, 1974, on the First Day of Their Formation. Arrow indicates composite center

storms in the early stages of development reveals that this is common. Vertical wind shear, which would produce such a cloud band, would be expected to inhibit tropical storm development.

1.5 Comparisons Between Type A, Type B, and Type D Storms

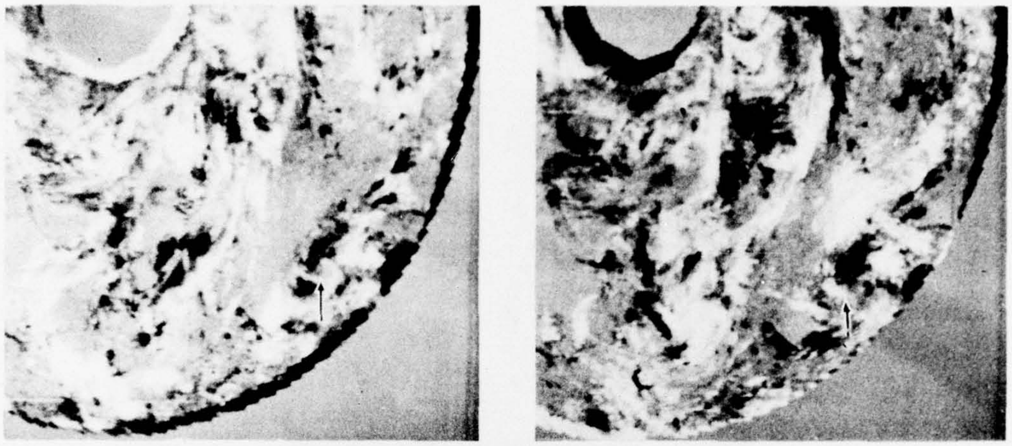
Mention has been made of the predominance of Type A storms and the fact that they tend to predominate in the fall. Further, while Type A storm tracks tend to congregate within a rather narrow, well-defined corridor, Type B and D storms are distributed all over the western Pacific. This geographic scattering of the Type B and D storms makes it difficult to select suitable and sizable samples from which to assemble composites and to generate differences between storms. Nevertheless several cases will be discussed; the storm data are listed in Table 5.

Table 5. Type A, B, and D Storms

Storm No.	Date	Type	Location*	Heading (deg)	Speed (kt)	Intensity
1	11/3/74	A	10N-140E	311	11	35
2	11/16/75	B	10N-140E	200	2	30
3	11/21/74	A	10N-140E	311	8	25
4(7)	8/14/74	D	25N-145E	317	10	50
5	9/5/75	B	25N-145E	320	9	95
6	11/10/75	B	25N-145E	022	18	75
7(4)	8/18/74	D	30N-125E	273	13	65
8(12)	10/4/75	B	30N-125E	065	16	95
9	8/2/75	D	25N-125E	280	14	80
10	9/21/75	D	25N-125E	280	13	65
11	7/3/74	B	25N-125E	322	10	75
12(8)	10/3/75	B	25N-125E	356	14	45

*Latitude and Longitude of northwest corner of 5-deg box in which it is located.

Figure 11 shows the differences between 2 Type A storms (Nos. 1 and 3) and the same Type B storm (No. 2) when all 3 are in an early stage of development. The lack of strong contrasts in the pictures indicates that there is very little difference. It is unfortunate that no suggestions as to the eventual course of the storms appear, though it is not surprising in view of the sample size and the undeveloped stage of the storm.



a b

Figure 11. Difference Between (a) Nov. 21, 1974 (Type A) and Nov. 16, 1975 (Type B); and (b) Nov. 3, 1974 (Type A) and Nov. 16, 1975. Arrow indicates composite center

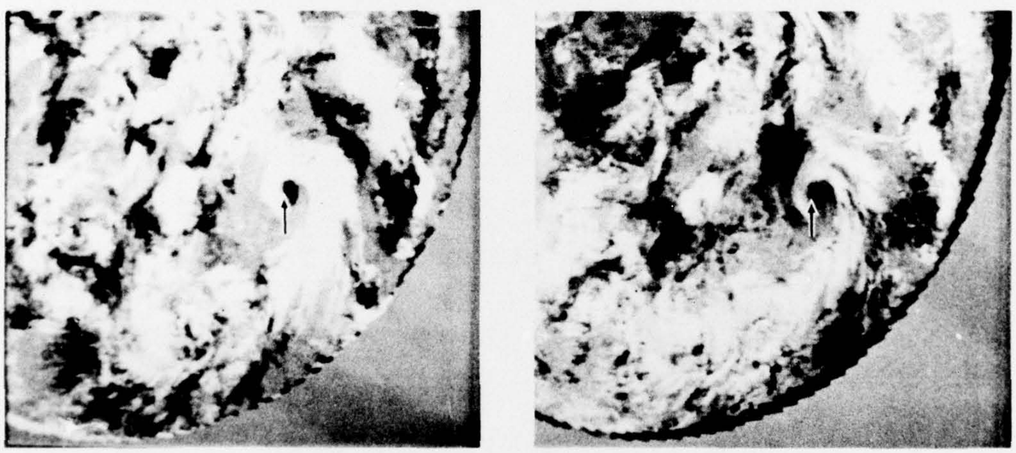


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Figure 12. Differences Between a Type D Storm on Aug. 14, 1974 and Type B on (a) Sept. 5, 1975 and (b) Nov. 10, 1975

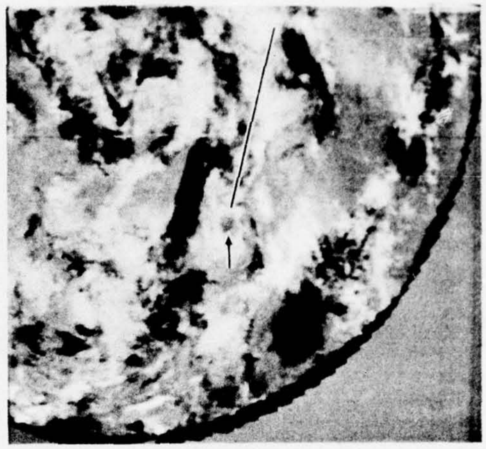

Figure 13. Difference Between Type D Storm on Aug. 18, 1974 and Type B on Oct. 4, 1975. Arrow indicates composite center. Black and white line is axis of confluent cloudiness.

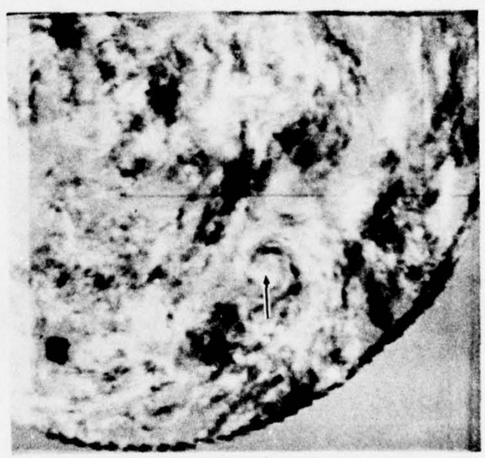

Figure 14. Difference Between 2 Type D Storms on Aug. 2 and Sept. 21, 1975 and 2 Type B Storms on July 3, 1974 and Oct. 3, 1975. Arrow indicates composite center

Figure 12 shows the differences between a Type D and 2 Type B storms. The Type D storm (No. 4) originated Aug. 11, 1974 near $17^{O}N$, $152^{O}E$ and traveled northwest to $26^{O}N$, $142^{O}E$ and thence westnorthwest into the China coast at about $29^{O}N$. In its early stages it was similar to a Type B and in its late stages to a Type A storm. Storm No. 5 was heading northwestward and would not recurve for about 24 hours, while storm No. 6 was at the point of recurvature. The primary feature in the difference fields is the extent of the cirrus outflow to the east and south of the Type D storm compared with the Type B's. Both systems had little cloudiness to the west as indicated by the gray shading. Storm No. 6, at the point of recurvature (Figure 12b), however, had cloudiness (dark area) north of the center and extending northeastward while storms Nos. 4 and 5 (Figure 12a) were both clear. Possibly the recurvature of storm No. 6 was related to the passage of a frontal system to the north. If so, this would be a sufficient (though not necessary) condition for recurvature since storm No. 5 did not display any confluence of its cloudiness with a frontal system around the time of its recurvature.

Four days later storm No. 4 had moved 20 deg westward as is identified in Table 5 as storm No. 7. In Figure 13 it is compared with a Type B storm (No. 8), which is at the point of recurvature. Certain features of Figure 13 strongly resemble those of Figure 12. Storm No. 7 still shows the effects of extensive outflow to the south. The source has been cut off by this time and it is clear to the east. Also, comparable with Figure 12b is the clear area northwest of the center but which here extends to the northeast and southwest. The point should be made that storm No. 7 was moving westward like the Type A storms to the south, and it also appears to be developing the confluent cloudiness associated with Type A storms. A suggestion of this feature remained until the storm made a landfall 2 days later.

Figure 14 also illustrates the difference between westward moving Type D storms (Nos. 9, 10) and Type B storms (Nos. 11, 12). Storm No. 12 is the same as No. 8 but one day earlier. The outflow cloudiness in the eastern and southern quadrants, that was discussed with respect to the Type D cases in Figures 12 and 13, is also observable in Figure 14 as is the clear band north of the storm generated cloudiness.

5. CONCLUSIONS

The availability of the McIDAS system encouraged the compositing approach used in this study. The approach has demonstrated a potential that was desired but unanticipated within the limitations of the data and time. Cloud features have been identified as associated with the direction of storm movement. Particularly in the case of distinguishing whether low-latitude storms will travel westward into

the South China Sea or take another heading, the results of the analysis approach significance. There is too consistent an appearance of the confluence of the storm outflow with frontal cloudiness to be dismissed offhand as coincidental.

There were not sufficient cases of other types of storms to claim anything but a suggestion of a relationship, yet in the case of the Type D storms, there was a consistency that followed one storm through 4 days (Aug 14-18, 1974) and 1000 miles. This feature of extensive outflow cloudiness to the east and south also occurred in similar-tracking storms at other times and places.

Further progress in this work will depend heavily on enlarging the data sample. There is the possibility though, that different analytical methods can help overcome the data shortage. For example, the use of infrared has several possible advantages, namely:

(a) it generates twice as many observations,

(b) allows the investigation of the significance of diurnal changes in the storm associated cloudiness,

(c) presents a less complex cloud field because of its emphasis on high clouds (this could also be a disadvantage).

The twice-daily availability of infrared also raises the possibility of utilizing the animation feature of McIDAS in the analysis. Test loops made from the visible data, once a day, did give an impression of continuous motion and development and bring out features of the circulation not at all apparent from still photographs.

In this study both a tool and a technique have demonstrated their utility. Adaptations of the technique to other weather identification or forecasting problems can easily be seen. The data used in this study were very crude in both space and time resolution. By utilizing the high space and time resolution data available from geosynchronous satellites, one can visualize an entirely new approach to the forecasting of some specific meteorological features based on the techniques used in this study.

References

1. Arnold, C. P., Jr. (1975) Selective reconnaissance program of the western north Pacific, B. Amer. Met. Soc., 56:362-371.

2. Dvorak, V. F. (1975) Tropical cyclone intensity analysis and forecasting from satellite imagery, Mon. Wea. Rev., 103:420-430.

3. Shea, D. J. (1972) The Structure and Dynamics of the Hurricane's Inner Region, Contract Report NOAA N 22-65-72(G), NSF GA 19937, Col. St. Univ., Atmos. Sci. Paper No. 182.

4. Suomi, V. E. (1975) Man-computer Interactive Data Access System (McIDAS). Continued Development of McIDAS and Operation in the GARP Atlantic Tropical Experiment. Final Report, Contract No. NASA-CR-143818, Wisconsin Univ.

5. National Oceanic and Atmospheric Administration (1973) Environmental Satellite Imagery, Key to Meteorological Records Documentation.

6. Joint Typhoon Warning Center (1973) Annual Typhoon Report, 1973, Fleet Weather Central, Guam, Marianas Is.

7. Joint Typhoon Warning Center (1974) Annual Typhoon Report, 1974, Fleet Weather Central, Guam, Marianas Is.

8. Joint Typhoon WarningCenter (1975) Annual Typhoon Report, 1975, Fleet Weather Central, Guam, Marianas Is.